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Estimating Improvement in Spawning Potential Ratios for South Atlantic Red Drum through Bag and Size Limit Regulations

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Abstract.—Based on a recent stock assessment of red drum *Sciaenops ocellatus* along the southern U.S. Atlantic coast (South Carolina to Florida), we calculated the possible gains in the static spawning potential ratio (SPR) from fishing mortality reductions (savings) produced by changing slot (size) and bag limits. Our method for calculating savings provides flexibility to address differences in commercial and recreational fishery regulations, regional stock conditions, and specific gear characteristics, and to account for discard mortality. Gear- and age-specific estimates of fishing mortality rates (F) for 1992–1997 resulted in savings from recreational fishery bag limits given a particular slot size. Relative changes in catch-at-age estimates modified the age-specific F estimates and, hence, the calculated SPR values. Additionally, recreational savings was adjusted to account for a release mortality of 10%. Static SPRs were estimated for (1) bag limits with increasing minimum size limits and a fixed maximum size and (2) bag limits with decreasing maximum size limits and a fixed minimum size. If the current slot limit (14–27 in total length) for the southern region remains unchanged, a bag limit of one fish per angler-trip would be required to attain the stated target of a 40% static SPR specified by the South Atlantic Fishery Management Council. However, the council's target could be attained with higher bag limits if the maximum size limit were reduced from the current level of 27 in, assuming no increase in effort on legal-size fish.

Red drum *Sciaenops ocellatus* is an estuarine-dependent species that inhabits coastal and oceanic waters and ranges from southwestern Florida to Mexico in the Gulf of Mexico and from Florida to Massachusetts along the U.S. Atlantic coast (Mercer 1984). The distribution of adult and subadult red drum is apparently determined by habitat type: subadult red drum inhabit shallow coastal estuarine environments and move into the deeper oceanic environment during maturation. Spawning occurs during summer and early fall. The adults are often found in large schools, which move inshore and offshore seasonally, whereas subadults remain in estuaries throughout the year. Estimates of natural mortality (M) for subadults and adults, age-specific fishing mortality (F), growth rates in length and weight, sex ratios, and age at maturity (Table 1) were detailed in the most recent red drum stock assessment (Vaughan and Carmichael 2000).

Early stock assessments treated the red drum along the U.S. Atlantic coast as a single stock (Vaughan and Helser 1990; Vaughan 1992). More recent assessments (Vaughan 1993, 1996; Vaughan and Carmichael 2000) have divided this stock into northern (U.S. coastal waters of North Carolina and northward) and southern (from South Carolina to the eastern coast of Florida) regions. A major difference between the two regions is that the northern region supports a commercial fishery (primarily in North Carolina and, to a lesser extent, Virginia). Results from the most recent stock assessment (Vaughan and Carmichael 2000) provide the basis for estimating the benefits from modification of bag and size limits. To highlight the approach, and for sake of simplicity, the bag and size limit analyses presented here apply only to the southern region.

In 1990, the South Atlantic Fishery Management Council (SAFMC) defined a 30% static

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TABLE 1.—Life history data for calculating static spawner potential ratio (Vaughan and Carmichael 2000). The linear von Bertalanffy growth equation is defined as $L_t = (b_0 + b_1 t)\{1 - \exp[-k(-t - t_0)]\}$, where L_t is total length at time t; the weight–length equation is $W_t = a(L_t)^b$, where W_t = whole weight in pounds at age t.

Parameter	Southern region estimate
Natural mortality (M)	
Subadults (ages 1–5)	0.23
Adults (ages 6–60)	0.13
Linear von Bertalanffy equation	
b_0	39.76
b_1	0.069
k	0.284
L_∞	−0.398
Weight–length	
a	0.00115
b	2.627
Proportion females	
Ages 1–2	0.50
Ages 3–60	0.61
Proportion females mature	
Age 1	0.0
Age 2	0.01
Age 3	0.58
Age 4	0.99
Ages 5–60	1.0

spawning potential ratio (SPR) as the target and threshold for overfishing (SAFMC 1990). More recently, a 40% static SPR was defined as the target level, with the 30% SPR remaining as the threshold for overfishing (Appendix A in Vaughan and Carmichael 2000). Management actions (Table 2) were initiated in 1992 through the Atlantic States Marine Fisheries Commission to raise static SPR for Atlantic red drum from the very low levels (~1%) estimated for 1986–1991 (Vaughan 1993) to above 10% (McGurrin 1991). At that time, Florida already had a one-fish bag limit, with an 18–27-in total length (TL) slot limit. Georgia and South Carolina each introduced a five-fish bag limit and 14–27-in slot limit in 1992. Based on the recent estimate (Vaughan and Carmichael 2000) of stock status relative to the SAFMC benchmark, overfishing is occurring on stocks of Atlantic red drum in both regions, with the best estimate of static SPR at about 15% for the southern region.

In this study, we evaluated the impacts of stricter bag and size limits on the SPR for south Atlantic red drum, based on conditions in the southern region during 1992–1998. "Savings" are defined here as the proportion of fish in the historical database that would not have been landed if a given management option had been in place at that time. Because SPR is a function of age-specific maturity,

TABLE 2.—State-specific management regulations in effect during 1992–1998 for the southern region Atlantic red drum. Size limits are total lengths in inches (modified from Appendix A in Vaughan and Carmichael 2000).

State	Size limit (in) Minimum	Size limit (in) Maximum	Bag limit	Gamefish status
Florida	18	27	1	No sale
Georgia	14	27	5	
South Carolina	14	27	5	No sale

weight, and mortality schedules, whereas regulatory savings only reflect changes in the number of fish harvested (i.e., the exploitation rate), changes in harvest and SPR are not equivalent. Therefore, regulation-based adjustments to mean fishing mortality rates were used to estimate SPR for the alternative bag and size limits.

Methods

Values of age-specific fishing mortality (F) from the latest stock assessment provided to the SAFMC for use in the bag and size analyses, were based on recommendations of the Red Drum Assessment Group (technical committee of the SAFMC; Appendix A in Vaughan and Carmichael 2000). The Red Drum Assessment Group selected the preferred catch matrix (DELTA approach for determining size frequency of recreational catch-and-release red drum[1]) and the FADAPT version of virtual population analysis (VPA; Restrepo 1996) as most appropriate from Vaughan and Carmichael (2000). Best estimates of equilibrium or static SPR (Gabriel et al. 1989) were obtained from specific selectivity assumptions chosen by the Red Drum Assessment Group (e.g., a selectivity of 0.87 for age 3 relative to age 2 in the final year, for the southern region). The FADAPT program requires an assumption of relative selectivity between two ages in the final year.

Our general approach was to determine the savings, by TL intervals, gained from more stringent size and bag limits. Age–length keys (Ricker 1975) were used to convert savings by size to age-based savings. Age-based savings were then used to modify age-specific estimates of F from Vaughan

[1] The DELTA approach used the difference in pooled length–frequency distributions from the Marine Recreational Fishery Statistical Survey, before (1986–1991) and after (1992–1998) changed management regulations, to approximate the size distribution of regulatory discards (B2 for the recreational fishing component).

and Carmichael (2000). Modified F estimates were used to estimate SPR (Gabriel et al. 1989) for the southern region under more restrictive management options.

Data used for the analyses were from Vaughan and Carmichael (2000) for 1992–1998, when management was approximately constant for the southern region. Data include (1) age-specific estimates of F; (2) catch in numbers at age by fishery and gear; (3) length-frequency data by fishery and gear; (4) catch per angler-trip from the recreational fishery; and (5) age–length keys. Detailed catch-at-age data permitted separation of age-specific F into that associated with each fishery and gear. Savings from bag and size regulations calculated by 1-in TL intervals were subsequently converted to relative savings by age based on age–length keys derived from pooled age–length data (Vaughan and Carmichael 2000). Savings by age were used to determine age-specific estimates of F for different combinations of bag and size regulations. Modified estimates of F for ages 1–5 were used in conjunction with estimates of natural mortality (M) for subadults and adults, growth, sex ratios, and maturity (Table 1) to estimate static SPR.

Data components and manipulations.—Estimates of age-specific F (Vaughan and Carmichael 2000) from 1992 to 1997 were averaged for the southern region. Age-specific F estimates for 1998 were excluded because of concerns about potential retrospective bias (i.e., increased error associated with VPA estimates for the most recent years of an assessment; Ulltang 1977; Sinclair et al. 1990).

Age-specific F was separated into various components of the recreational and commercial fisheries. Estimates of F at age j associated with each fishery component or gear g ($F_{j,g}$) were based on the proportion of catch ($C_{j,g}$) as used in developing the catch matrix:

$$F_{j,g} = \frac{C_{j,g}}{\sum_{g} C_{j,g}} \cdot F_j. \qquad (1)$$

Fishing mortality for the recreational fishery was separated into retained (caught) and discarded (released) fish. The Marine Recreational Fisheries Statistics Survey (MRFSS) categorizes fish as either retained and available for measurement (type A), retained and not available for measurement (type B1), or discarded (type B2; Essig et al. 1991). Discarded and retained fish are separated because savings associated with increasing constraints on bag and size limits would accrue to the retained fish, which would be released in greater numbers, but not to the discarded fish. Separation of F into commercial fishery gears for the southern region included some residual line gears. Because commercial landings (hook and line only) represented about 0.2% of total landings during 1992–1998, they were pooled with the retained recreational landings.

Length-frequency distributions by 1-in TL interval i and gear g ($L_{i,g}$) were obtained from Vaughan and Carmichael (2000). Distributions for both recreational retained and discarded fish were available.

Catch frequencies were obtained from MRFSS recreational intercept data on catches per angler-trip during 1992–1998 (Essig et al. 1991). Some adjustments were necessary because of two situations: (1) some trips involved multiple anglers, and (2) not all retained red drum were measured. For trips involving multiple anglers, and with more anglers than fish, one fish was assigned per angler up to the total caught (i.e., 10 fish caught among 12 anglers were considered 10 angler-trips with one fish for each trip). For trips involving multiple anglers, and with more fish than anglers, the number of fish was divided by the number of anglers and rounded to an integer as needed (i.e., six fish caught by three anglers would equal three angler-trips, with two fish per angler-trip). Unmeasured, retained fish were assigned to 1-in TL intervals in the same proportions as measured fish. Trips without any fish measurement data were deleted from the bag and size limit analyses.

Savings from bag limit modifications were calculated from historical catch per angler-trip by reducing the number caught to the modified bag limit. The total catches with and without the modified bag limit were then compared. The difference between the two catches, divided by the total historical catch, represents the savings from the new bag limit relative to historical conditions.

Alteration of the slot limit will also produce savings; however, we considered slot and bag limits separately in our analyses. To avoid confounding the effects of slot and bag limits, bag-limit savings are estimated contingent on the corresponding slot limit.

Application of age–length keys to the length-frequency data transformed fish sizes into ages. Age–length keys ($A_{i,j}$, where length interval i = 7–41 in TL and age j = 1–6+) were developed from pooled age and length data (1992–1998) for the southern region (Vaughan and Carmichael 2000).

Savings calculations.—Our approach for calculating savings from modifications to bag and size limits was to specify savings in 1-in TL intervals. The cross product of the length-frequency ($L_{i,g}$) and age columns from the age–length key $A_{i,j}$ for each 1-in TL interval provided an index of catch at age (this would equal the catch in numbers at age for a given gear if multiplied by the total number caught by that gear). A corresponding index of the catch at age saved by regulatory changes was calculated from the cross product of the length frequency $L_{i,g}$, the corresponding age column $A_{i,j}$, and the proportion saved ($S_{i,g}$) for each 1-in TL interval. The ratio of the two indices by age allows modification of the age-specific estimates of F to reflect the modified bag and size limit regulations for the specific gear.

Expressed mathematically, we define $L_{i,g}$ as the proportion of fish in 1-in TL interval i sampled from gear g, that is,

$$\sum_i L_{i,g} = 1, \tag{2}$$

$A_{i,j}$ equals the proportion of fish of age j in length interval i, such that for all length intervals,

$$\sum_j A_{i,j} = 1. \tag{3}$$

Hence, an index of the catch at age j sampled by gear g ($I_{j,g}$) is given by

$$I_{j,g} = \sum_i L_{i,g} \cdot A_{i,j}. \tag{4}$$

If we define size-specific savings $S_{i,g}$ for each length interval i and gear g, then an index of saved catch for age j from gear g is given by

$$I^*_{j,g} = \sum_i L_{i,g} \cdot A_{i,j} \cdot S_{i,g}. \tag{5}$$

Multiplying this index by the release survival $\delta_{i,g}$, where $1 - \delta_{i,g}$ equals the size- and gear-dependent release mortality, allows for adjustment (reduction) in catch savings for fish that are caught and released but that subsequently die. Allowing for release mortality across sizes and gears, an adjusted index of saved catch for age j from gear g (${}_aI^*_{j,g}$) is given by

$${}_aI^*_{j,g} = \sum_i \delta_{i,g} \cdot L_{i,g} \cdot A_{i,j} \cdot S_{i,g}. \tag{6}$$

The ratio ${}_aI^*_{j,g}/I_{j,g}$ represents the adjusted savings in catch for age j from gear g. Adjusted age- and gear-specific mortality ($F^*_{j,g}$) is calculated by multiplying age- and gear-specific mortality $F_{j,g}$ by one minus the adjusted savings for use in subsequent population models:

$$F^*_{j,g} = \left(1 - \frac{{}_aI^*_{j,g}}{I_{j,g}}\right) \cdot F_{j,g}. \tag{7}$$

For discarded fish, there are no savings in F from changing bag and size limits, so

$$F^*_{j,B2} = F_{j,B2}. \tag{8}$$

Adjusted age-specific mortality (F^*_j) that reflects savings from bag and size limits across all gears is obtained by summing estimates for these gears:

$$F^*_j = \sum_g F^*_{j,g}. \tag{9}$$

Developing the savings vector $S_{i,g}$ for the recreational fishery is fairly straightforward. We assume 100% compliance with the size and bag restrictions, and a release mortality of 10% (as in Vaughan and Carmichael 2000). For length intervals outside the modified slot limit, for which no retained catches are permitted, savings equal the release survival by gear for originally retained fish and equal zero for discarded fish. Applying the 10% release mortality for retained fish, the release survival is 90%. Hence, savings for fish outside the slot would be 0.9 (or 90%). Savings for length intervals within the slot are based on the bag limit, but are reduced by release mortality. Thus, the release survival multiplied by savings from the bag limit associated with a given slot limit (e.g., 0.9 times bag limit savings) gives the estimated savings for these sizes.

Static, or equilibrium, SPR is the primary approach for measuring the intensity of red drum exploitation (Gabriel et al. 1989; Gulf of Mexico Spawning Potential Ratio Management Strategy Committee 1996). The static SPR approach calculates the spawning stock biomass (or other measures of reproductive strength) under fishing and nonfishing conditions. Table 1 summarizes the life history parameters needed for estimating static SPR, including natural mortality for subadults and adults, parameters from the growth equation and weight–length relationship ($W = aL^b$), sex ratios, and maturity schedules. Static SPR, expressed as a percentage, is given by

Static SPR

$$= 100 \cdot \frac{\sum_j s_j \cdot m_j \cdot w_j \prod_{i=1}^{j} \exp(-M_i - F_i)}{\sum_j s_j \cdot m_j \cdot w_j \prod_{i=1}^{j} \exp(-M_i)}, \tag{10}$$

TABLE 3.—Estimates of the instantaneous fishing mortality rate (F) for Atlantic red drum for the southern region from Vaughan and Carmichael (2000) using virtual population analysis on DELTA catch matrix with selectivity of $F_3 = 0.87 \cdot F_2$ in the final year. Age-specific estimates of F are separated by fishery based on catch of numbers at age.

Age	F (1/year)	Recreational		Commercial
		Retained	Released	
1	0.141	0.069	0.072	0.000
2	0.459	0.336	0.122	0.001
3	0.584	0.576	0.006	0.002
4	0.592	0.584	0.006	0.002
5	0.361	0.348	0.012	0.001

where the instantaneous natural mortality rate M and the instantaneous fishing mortality rate F are needed for ages 1–60 (for subadults, M is constant for ages 1–5, and for adults it is constant for ages 6–60), the proportion of females (s_j) and the proportion of females mature at age (m_j) are used to determine proportion of mature females for ages 1–60, and weight for ages 1–60 (w_j) is determined by first calculating length at age from the growth equation and then calculating it from the weight–length relationship. As in past assessments (e.g., Vaughan 1993, 1996; Vaughan and Carmichael 2000), F for ages 6–60 is assumed to equal zero, which may lead to overestimation of static SPR.

Results

Age-specific estimates of original F were from the VPA applied to the DELTA catch matrix, with a selectivity of F_3 equal to $0.87F_2$ in the final year. Estimated values of F were then averaged over the period 1992–1997 (Table 3). Based on the mean catch in numbers at ages 1–5 for 1992–1998, the age-specific estimates of F were separated into three components (recreational retained, recreational discarded, and residual commercial lines) based on equation (1) (Table 3). Essentially, all landings were from the recreational fishery (99.8%), with only 0.2% identified as originating from commercial line gears. Hence, only two components were needed, because the few commercial landings could all be classified as hook-and-line and could be pooled with the recreational retained component.

The length distributions represent the proportion of catch in numbers in each 1-in TL interval from 7 through 41+ in, pooled across years for 1992–1998 (Figure 1). The size selectivity in the recreational length frequencies results from the slot limit. Frequency of catch per angler-trip from the

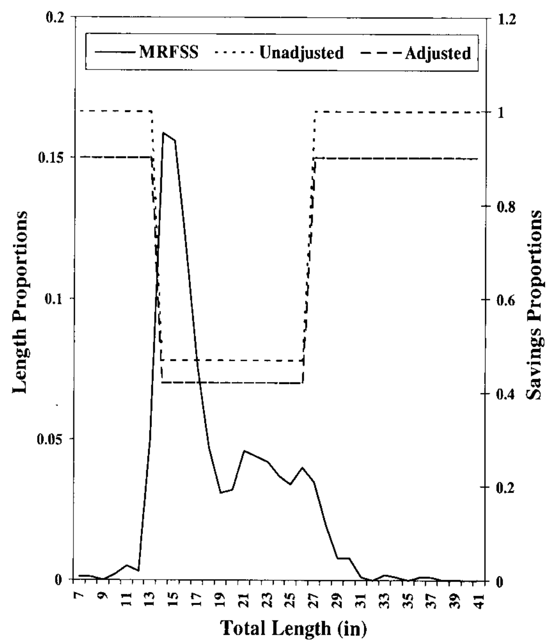

FIGURE 1.—Atlantic red drum length-frequency distribution for recreational landings from the southern region (sample size of intercepted fish equals 2,403) from the Marine Recreational Fisheries Statistical Survey (MRFSS), 1992–1998. Also shown is the sample savings vector for a proportional reduction in size-specific fishing mortality rate (with and without adjustment for release mortality) for recreationally retained red drum by TL intervals, based on a 14–27-in slot limit with a one-fish bag limit.

recreational database suggested that, during 1992–1998, most anglers caught only one red drum per trip (60.5% of angler-trips; Figure 2). The sample size was 1,769 angler-trips, with 36 trips reporting in excess of five fish and one trip reporting 16 fish.

Savings from bag limits were calculated from recreational data on retained and discarded fish, along with associated data on catch per angler-trip and size of fish. For the period 1992–1998, the sample size was 3,244 fish. The number of red drum caught and retained for different bag limits was calculated with two variations on slot limits. First, the minimum size limit was allowed to vary between 14 and 20 in TL in 1-in intervals, with a fixed maximum size limit of 27 in TL (Table 4). Second, the maximum size limit was allowed to vary between 21 and 27 in TL in 1-in intervals, with a fixed minimum size limit of 14 in TL (Table 5). Savings from the bag limits were calculated separately relative to the imposed slot limit. For example, a one-fish bag limit with a 14–27 in TL slot limit (see Table 4) would produce savings,

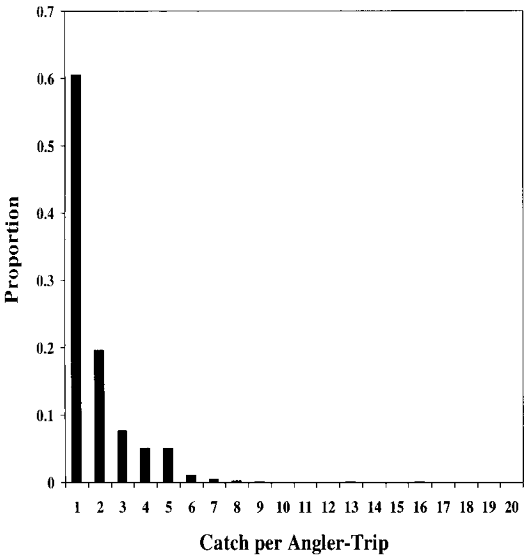

FIGURE 2.—Frequency of catch of Atlantic red drum per angler-trip for the southern region, 1992–1998.

before adjustment for release mortality, of 46.8% of the catch of red drum larger than 14 in (100 × [1,516/2,848]). A total of 2,848 fish would have been retained with the 14–27 in TL slot limit, of which 1,516 fish would have been retained with the one-fish bag limit.

Age–length data included information from South Carolina (94%), Georgia (5%), and the eastern coast of Florida (1%). Sample size for the age–length key (n = 29,347) was high, generally more than 10 fish per 1-in TL interval (Table 6). Sample sizes in the key were only inadequate at the largest lengths (38–40 in; assigned to age 5 or age 6+), which exceeded the legal maximum.

Estimates of age-specific F were separated into recreational retained and recreational discarded components. Because recreational discarded fish were not retained in the first place, estimates of F associated with this component were not modified by changes to bag and size limits (equation 8). Age-specific estimates of F associated with retained catch were modified by the savings for each 1-in TL interval. An example savings vector portrays a slot limit of 14–27 in TL with a one-fish bag limit (Figure 1). Values for 1-in intervals less than or equal to 14 in TL and greater than or equal to 27 in TL are represented by 1.0, which represents complete savings. The savings from the slot limit (14 in TL up to, but not including, 27 in TL) is given as 0.468 (Table 4). Savings were adjusted for release mortality by replacing $\delta_{i,A+BI}$ in equation (6) with 0.9 for all values of i, implying a release mortality of 10% and release survival of 90%. Age-specific F for recreational retained fish was then modified by 1.0 minus the ratio of the adjusted index of saved fish $_{a}I^{*}_{j,g}$ to the index of caught fish $I_{j,g}$ (equation 7). Age- and gear-specific estimates of F were combined, as in equation (9). The estimates of age-specific F were calculated for a range of bag limits with either increasing minimum size limits (Table 7) or decreasing maximum size limits (Table 8). Estimates of age-specific F, combined with life history parameters (Table 1), were used to estimate static SPR (equation 10).

TABLE 4.—Number of southern region Atlantic red drum that would have been caught and retained from the recreational fishery and savings accrued for a range of slot sizes with an increasing minimum size limit, 1992–1998 (the maximum size = 27 in total length). Note that the "no slot" and "no bag" categories represent the underlying conditions for 1992–1998: a five-fish bag limit and a 14–27-in slot limit in South Carolina and Georgia and a one-fish bag limit and an 18–27-in slot limit in Florida.

Bag limit (number of fish)	No slot	Minimum size limit (in) 14	15	16	17	18	19	20
	Number caught and retained if slot/bag limits were in place							
1	1,770	1,516	1,344	1,126	928	783	694	629
2	2,468	2,127	1,828	1,466	1,186	973	849	765
3	2,820	2,453	2,083	1,620	1,309	1,066	927	830
4	3,037	2,656	2,237	1,721	1,377	1,115	967	864
5	3,164	2,772	2,319	1,780	1,414	1,149	995	889
No bag	3,244	2,848	2,356	1,809	1,443	1,171	1,017	911
	Proportion saved by bag limit relative to slot limit (unadjusted for release mortality)							
1	0.454	0.468	0.430	0.378	0.357	0.331	0.318	0.310
2	0.239	0.253	0.224	0.190	0.178	0.169	0.165	0.160
3	0.131	0.139	0.116	0.104	0.093	0.090	0.088	0.089
4	0.064	0.067	0.051	0.049	0.046	0.048	0.049	0.052
5	0.025	0.027	0.016	0.016	0.020	0.019	0.022	0.024

TABLE 5.—Number of southern region Atlantic red drum that would have been caught and retained from the recreational fishery and savings accrued for a range of slot sizes with decreasing maximum size limit, 1992–1998 (the minimum size = 14 in total length). See the caption to Table 4 for additional details.

Bag limit	No slot	Maximum size limit (in)						
		21	22	23	24	25	26	27
		Number caught and retained if slot/bag limits in place						
1	1,770	1,081	1,161	1,238	1,317	1,386	1,443	1,516
2	2,468	1,542	1,640	1,747	1,862	1,946	2,030	2,127
3	2,820	1,781	1,896	2,025	2,157	2,255	2,351	2,453
4	3,037	1,920	2,038	2,185	2,325	2,447	2,550	2,656
5	3,164	1,994	2,116	2,272	2,415	2,549	2,658	2,772
No bag	3,244	2,050	2,172	2,330	2,473	2,613	2,723	2,848
		Proportion saved by bag relative to slot limit (unadjusted for release mortality)						
1	0.454	0.473	0.465	0.469	0.467	0.470	0.470	0.468
2	0.239	0.248	0.245	0.250	0.247	0.255	0.254	0.253
3	0.131	0.131	0.127	0.131	0.128	0.137	0.137	0.139
4	0.064	0.063	0.062	0.062	0.060	0.064	0.064	0.067
5	0.025	0.027	0.026	0.025	0.023	0.024	0.024	0.027

TABLE 6.—Atlantic red drum age–length key for the southern region, 1992–1998 (n = 29,347).

Total length (in)	Sample size	Age (years)					
		1	2	3	4	5	6+
7	37	0.892	0.108				
8	51	0.980	0.020				
9	231	0.996	0.004				
10	852	0.991	0.005	0.005			
11	800	0.996	0.003	0.001			
12	861	0.983	0.008	0.009			
13	1,048	0.933	0.065	0.002			
14	1,848	0.682	0.315	0.002	0.001		
15	2,860	0.459	0.539	0.001	0.0		
16	2,542	0.360	0.638	0.002	0.0		
17	1,641	0.255	0.745	0.001	0.0		
18	792	0.106	0.888	0.005	0.001		
19	674	0.034	0.904	0.062	0.0		
20	763	0.004	0.769	0.227	0.0		
21	1,152	0.006	0.601	0.392	0.001		
22	1,613	0.001	0.460	0.534	0.005		
23	1,789	0.002	0.373	0.605	0.020		0.001
24	1,872	0.001	0.207	0.705	0.085	0.002	0.001
25	1,573		0.126	0.670	0.196	0.008	0.0
26	1,218		0.045	0.506	0.413	0.035	0.001
27	1,155		0.010	0.349	0.539	0.099	0.003
28	1,025		0.002	0.235	0.571	0.189	0.003
29	949		0.001	0.109	0.581	0.298	0.012
30	781		0.003	0.069	0.579	0.327	0.023
31	485		0.002	0.035	0.555	0.363	0.045
32	302			0.020	0.487	0.437	0.056
33	170			0.012	0.353	0.418	0.218
34	99			0.0	0.364	0.424	0.212
35	60			0.017	0.133	0.367	0.483
36	34				0.059	0.206	0.735
37	18				0.056	0.056	0.944
38	6					0.167	0.833
39	11					0.0	1.0
40	7					0.0	1.0

TABLE 7.—Adjusted estimates of age-specific fishing mortality rates for increasing minimum size limits (maximum size = 27 in total length) and varying bag limits for southern region Atlantic red drum.

Age (years)	Minimum size limit (in) 14	15	16	17	18	19	20
			One-fish bag limit				
1	0.105	0.095	0.087	0.082	0.079	0.079	0.079
2	0.316	0.307	0.285	0.256	0.234	0.217	0.204
3	0.310	0.327	0.351	0.360	0.371	0.377	0.377
4	0.178	0.186	0.197	0.201	0.206	0.209	0.210
5	0.065	0.066	0.068	0.069	0.070	0.070	0.071
			Two-fish bag limit				
1	0.116	0.101	0.090	0.083	0.080	0.079	0.079
2	0.380	0.362	0.325	0.284	0.253	0.230	0.214
3	0.409	0.422	0.437	0.442	0.446	0.447	0.444
4	0.224	0.229	0.236	0.239	0.240	0.241	0.242
5	0.073	0.074	0.075	0.075	0.075	0.076	0.076
			Three-fish bag limit				
1	0.122	0.104	0.091	0.083	0.080	0.079	0.079
2	0.414	0.391	0.342	0.298	0.263	0.237	0.219
3	0.462	0.472	0.476	0.481	0.482	0.482	0.477
4	0.248	0.252	0.254	0.257	0.257	0.257	0.257
5	0.077	0.077	0.078	0.078	0.078	0.078	0.078
			Four-fish bag limit				
1	0.125	0.105	0.092	0.084	0.080	0.079	0.079
2	0.436	0.408	0.354	0.305	0.268	0.240	0.222
3	0.495	0.502	0.502	0.503	0.502	0.500	0.493
4	0.263	0.266	0.266	0.267	0.266	0.265	0.265
5	0.079	0.080	0.080	0.080	0.080	0.080	0.080
			Five-fish bag limit				
1	0.127	0.106	0.092	0.084	0.080	0.079	0.079
2	0.448	0.418	0.361	0.309	0.271	0.243	0.224
3	0.514	0.518	0.517	0.515	0.515	0.513	0.506
4	0.272	0.274	0.273	0.272	0.272	0.271	0.271
5	0.080	0.081	0.081	0.081	0.081	0.081	0.081

A bag limit of one fish per angler-trip would be required to attain the stated target of a 40% static SPR if the current slot limit is not changed. Increases in the minimum size limit above 14 in TL, while the maximum size limit of 27 in TL was maintained, did not achieve the stated SPR target level with bag limits greater than one fish (Table 9). However, when the minimum size limit was maintained at 14 in TL while the maximum size limit was reduced from 27 in TL (Table 9), higher bag limits were possible (e.g., a three-fish bag limit and 14–24 in TL slot limit) while attaining the stated SPR target level.

Discussion

Our review of the fishery literature on bag and size limits found that previous papers focused on measuring changes in catch rates and population parameters before and after the regulations were imposed and that most were largely freshwater oriented (e.g., Saila 1956; Novinger 1987; Austen and Orth 1988; Novinger 1990; Lyons et al. 1996, Munger and Kraai 1997; Newman and Hoff 2000; Nordwall et al. 2000; Fayram et al. 2001). We found no published studies that attempted to predict the a priori effects of bag and size limits on exploitation and static SPR of marine fishes. The purpose of this study was to provide guidance to managers for a range of potential bag size limits that may meet management criteria.

Because we made numerous assumptions in the original assessment (Vaughan and Carmichael 2000), and the present analysis uses results from that assessment, the size and bag limit analyses would be biased by any faulty assumptions. Assumptions involve the treatment of recreational discard losses (including catch-and-release mortality), age selectivity, and exploitation of the adult population. An approach was developed in the red drum stock assessment for estimating the size of released recreational fish, which were numerous during 1992–1998 for both northern and southern

TABLE 8.—Adjusted estimates of age-specific fishing mortality rates (F) for decreasing maximum size limits (minimum size = 14 in TL) and varying bag limits for southern region Atlantic red drum.

Age (years)	Maximum size limit (in) 21	22	23	24	25	26	27
			One-fish bag limit				
1	0.105	0.105	0.105	0.105	0.105	0.105	0.105
2	0.286	0.298	0.304	0.311	0.313	0.314	0.316
3	0.081	0.112	0.151	0.194	0.237	0.275	0.310
4	0.066	0.066	0.067	0.070	0.083	0.110	0.178
5	0.047	0.047	0.047	0.047	0.047	0.050	0.065
			Two-fish bag limit				
1	0.116	0.116	0.116	0.116	0.116	0.116	0.116
2	0.342	0.357	0.366	0.375	0.376	0.379	0.380
3	0.088	0.131	0.186	0.247	0.307	0.361	0.409
4	0.066	0.066	0.068	0.072	0.090	0.128	0.224
5	0.047	0.047	0.047	0.047	0.047	0.052	0.073
			Three-fish bag limit				
1	0.122	0.122	0.122	0.122	0.122	0.122	0.122
2	0.371	0.388	0.399	0.409	0.411	0.414	0.414
3	0.092	0.142	0.205	0.276	0.345	0.407	0.462
4	0.066	0.067	0.068	0.073	0.094	0.138	0.248
5	0.047	0.047	0.047	0.047	0.048	0.052	0.077
			Four-fish bag limit				
1	0.126	0.126	0.126	0.126	0.126	0.126	0.259
2	0.387	0.406	0.418	0.429	0.433	0.436	0.436
3	0.094	0.148	0.217	0.293	0.369	0.437	0.495
4	0.066	0.067	0.068	0.074	0.079	0.145	0.263
5	0.047	0.047	0.047	0.047	0.048	0.053	0.079
			Five-fish bag limit				
1	0.127	0.128	0.128	0.128	0.128	0.128	0.127
2	0.396	0.415	0.429	0.440	0.445	0.448	0.448
3	0.095	0.151	0.223	0.301	0.382	0.452	0.514
4	0.066	0.067	0.068	0.075	0.098	0.148	0.272
5	0.047	0.047	0.047	0.047	0.048	0.053	0.080

regions. The estimation of the selectivity of age 3 relative to age 2 in the final year was necessary for applying the VPA. Estimation of SPR depends, in part, on the age-specific estimates of F obtained from the stock assessment (Vaughan and Carmichael 2000), and the assumption that F equals zero for age-6 and older fish.

Because the bag limit was generally five or fewer red drum during 1992–1998 for the southern region, it was not possible to analyze the consequences of increasing the bag limit above this value. A similar constraint existed for slot limits, with 14–27 in TL defining the range in sizes for the southern region except for Florida (18–27 in TL slot limit). Because Florida was more restrictive than other states in the southern region (Table 2) during the period of interest, analyses of increasing restrictions on bag and size limits for the southern

TABLE 9.—Static spawning potential ratio (SPR) for a range of bag limits with an increasing minimum size limit and a decreasing maximum size limit for southern region Atlantic red drum. Numbers in bold are at or above the target SPR of 40% after rounding.

Bag limit	Increasing minimum size limit (in; maximum size = 27 in total length) 14	15	16	17	18	19	20	Decreasing maximum size limit (in; minimum size = 14 in total length) 21	22	23	24	25	26	27
1	**39.7**	**39.5**	39.4	**40.3**	**40.7**	**41.0**	**41.5**	**56.8**	**54.5**	**52.2**	**49.6**	**47.0**	**44.1**	**39.7**
2	32.1	32.6	33.5	34.9	36.0	36.8	37.4	**52.8**	**49.9**	**46.9**	**43.7**	**40.6**	37.1	32.1
3	28.7	29.5	31.2	32.7	33.9	34.8	35.6	**50.8**	**47.6**	**44.3**	**40.8**	37.4	33.8	28.7
4	26.8	27.8	29.8	31.4	32.8	33.9	34.7	**49.7**	**46.3**	**42.8**	39.2	35.6	31.8	26.8
5	25.7	26.9	28.9	30.8	32.1	33.2	34.0	**49.1**	**45.6**	**42.0**	38.3	34.6	30.8	25.7

region assume no relaxation of the bag and size limits within Florida. If Florida relaxed its restrictions, the potential savings would be overestimated by our analysis.

Two factors that would promote differences between realized and predicted savings are recent changes in effort and noncompliance with existing regulations. The factors are related to the baseline period (1992–1998) selected for the analyses and the time series of available data. Any change in effort since 1998 is not reflected in the results. Noncompliance can be significant (e.g., Pierce and Tomcko 1998) and has been demonstrated to significantly reduce potential yield-per-recruit (Gigliotti and Taylor 1990). Several cases of noncompliance were evident in our red drum data and led to a projected approximate 11% gain (26–15% static SPR) from the base regulations (five-fish bag limit and 14–27 in TL slot limit) (Table 9). Most of the gain comes from the few red drum larger than 27 in TL. No attempt was made to analyze future noncompliance with the regulations.

Other factors, such as delayed harvest and stock availability, can affect future realized savings, reflecting how the stock or its users may respond to the regulatory changes. Changes in minimum legal size may only delay harvest, especially when applied to a fast-growing species. For example, many of the red drum harvested in the southern region are close to the minimum legal size, implying that they are harvested soon after recruitment to the fishery (Figure 1). Although calculations based on the observed data suggest that a 1–2-in increase in the minimum size could provide substantial savings in the number of fish caught (Table 4), such savings are simply the result of protecting fish in the peak of the length distribution. In reality, because red drum grow rapidly within the range of 14–20 in TL, minor minimum size increases serve only to delay harvest a few months and therefore result only in small gains in predicted static SPR. While delayed harvest can occur with no change in angler behavior, recoupment occurs when anglers respond to stricter regulations by changing fishing methods or effort to maintain the total harvest level. We made no effort to anticipate such changes as increased trips or changes in fishing locations and fishing techniques; however, alterations in angler behavior could lead to differences between predicted and realized savings. Catch rates are related to both fishery regulations and stock abundance. Few trips result in catches of the five-fish bag limit, and most trips only land one or two fish, which may be an indication of low abundance of the stock for sizes within the slot limit. If regulatory changes achieve the desired result of increasing stock abundance, more anglers could potentially achieve the bag limit within a single trip. Further, if a regulatory strategy based largely on changes in the slot limit is selected to maintain a high possession limit, and future catch rates per trip approach that high possession limit instead of the one to two fish currently landed per trip, then future realized gains will likely be less than predicted.

Savings in number of fish caught is not directly related to improvements in static SPR. For instance, a large number of fish would be saved by increasing minimum size from 14 to 16 in TL, but for most bag limits, the savings of small fish provide relatively small gains in static SPR (Table 9). Conversely, decreasing maximum size limits produce much greater gains in static SPR than equivalent increases in minimum size limits. Savings of larger fish imply greater gains in static SPR, because the probability of survival to maturity is much higher for fish that have already survived the fishery effort. The higher survival probability results from older subadults encountering less cumulative mortality prior to reaching sexual maturity, and hence contributing greater mature biomass to static SPR.

Inclusion of commercial landings in bag and size limit analyses depends largely on data availability and on how the regulations are written. Typically, little or no information on size or quantity is available for at-sea discards (comparable to the recreational discarded fish). Also, release mortality for various commercial gears is often assumed to be 100%, but may be less for some gears (e.g., pound net or hook and line). If commercial fisheries were subject to the same slot and/or bag limits as recreational fisheries, then they could be included in bag and size limit analyses with appropriate data. If commercial fisheries were subject to size and trip limits, then additional information would be required on catch rates and size composition for individual trips.

Our method for calculating savings provides flexibility to address differences in fishery regulations, regional stock conditions, and specific gear characteristics, and to account for discard mortality. An important advancement is that we present the results of various regulations in the same "currency" (F at age and static SPR) as the management benchmarks, rather than simply as percentage reduction in harvest. Use of the same terms considerably simplifies the selection of appropriate management measures, and avoids incurring additional assumptions about the relationship between landings and exploitation rates. Analyses of regulatory changes often assume that changes in landings are equivalent to changes in exploitation rates. Such assumptions are invariably violated and would be violated for red drum, as evidenced by the differential impacts on catch and SPR for increasing minimum sizes and decreasing maximum sizes.

In conclusion, management measures enacted early in 1992 provided significant gains in estimates of SPR benchmarks for southern region red drum. However, more restrictions are needed to reach the SAFMC's stated target of 40% SPR. Selection of appropriate management measures should be guided by the potential SPR resulting from each measure, but must also consider the risks of recoupment and delayed harvest, as discussed above. Increasing the minimum size alone offers little improvement in SPR, and the suggested harvest reductions will likely be quickly recouped by anglers as the fish grow. Reducing the maximum size offers the biggest improvements in SPR without the risk of recoupment due to fish growth. However, the fact that few trips landed more than two red drum introduces a potential bias at higher possession limits, resulting in an opportunity for recoupment at the higher bag limits if either fish availability or angler success rate increases. Reducing the possession limit to one fish is clearly very effective, and could achieve the SPR target with no change in the slot limit. Although the bag limit reduction from five fish to one fish may be perceived as drastic, it is less so when the reality that few trips land more than two fish is considered. A major benefit from reducing the possession limit is that the suggested harvest savings can only be recouped if angler behavior changes significantly, through increased trips or participation.

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